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1336 Issued March 10, 1911.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS—CIRCULAR 108.
A. C. TRUE, Director.

SECOND PROGRESS REPORT OF COOPERATIVE IRRIGATION INVESTIGATIONS IN CALIFORNIA.

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[Review of work done in cooperation between the Office of Experiment Stations and the State of California.]

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1911.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., January 3, 1911.

Sir: I have the honor to transmit herewith a progress report of cooperative irrigation investigations in California, prepared by Frank Adams, under the direction of Samuel Fortier, chief of irrigation investigations of this Office. Irrigation investigations have been carried on in California for a number of years by cooperation between the State of California and this Office and it is now desirable that a summary of the work thus far accomplished be presented to the people of that State, as well as to others interested in such investigations. It is therefore recommended that the report be published as a circular of this Office.

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

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REPORT OF COOPERATIVE IRRIGATION INVESTIGATIONS IN CALIFORNIA.

The fiscal year ended June 30, 1910, was the tenth in which irrigation investigations have been carried on in California by the Office of Experiment Stations of the United States Department of Agriculture, and the seventh in which the work has been cooperative with the State of California.[a] A sufficient period of time has therefore been covered to warrant a summary and review of the work done.

THE WATER-RIGHT SITUATION IN CALIFORNIA.

No question relating to irrigation, in California or any other State, approaches in importance the speedy and certain determination of water rights, and consideration of this subject was the first irrigation work undertaken in this State by the Office of Experiment Stations.

That California has been less fortunate in her water-right laws than most of her sister States requiring irrigation has long been the settled conviction of those familiar with procedure elsewhere. The entire foundation of water rights in this State was laid when, at best, only a few thousand acres of land were irrigated, and before the future importance of irrigation in California was half realized. Then it seemed a most natural thing to frame into statute law the simple plan of merely posting a notice of appropriation and taking water, which the daily customs of pioneers had already established.

[a] In 1900 these investigations were carried on in cooperation with the California Water and Forest Association, and since July 1, 1903, one-half of the funds expended have been furnished by the State of California. From 1903 to 1909, California cooperated with the Office of Experiment Stations through the state board of examiners. In 1909 the investigations were placed on a more permanent footing by an act of the legislature, approved April 22, making a standing appropriation of $30,000 per annum for topographic surveys and investigations of the water resources of the State and empowering the department of engineering of the State to enter into contracts for cooperation along these lines with the different departments of the Federal Government interested. Since this enactment the Department of Agriculture, through the irrigation investigations of the Office of Experiment Stations, and the state engineering department, through the state engineer, have each appropriated $7,000 per annum in the prosecution of these investigations in California. In addition, the University of California has furnished state headquarters for the work in the agricultural building of the university, at Berkeley, and since 1907 has cooperated in irrigation experiments on the university farm, at Davis.

But this apparently simple plan of the pioneers, although copied and for a time followed by all of the Western States, has not proved an adequate foundation for water titles where water for irrigation possesses such overshadowing importance as it does in California. Resulting litigation has compelled irrigators and irrigation companies to spend millions of dollars protecting property which the State in its generosity sought to give freely. Realizing these things, several public spirited attempts have been made from time to time to provide a plan that would prove adequate—that would enable an appropriator of water for beneficial use to acquire without protracted litigation a water title as stable as his land title, and at the same time insure the full and proper use of the last acre-foot or gallon of water available for, and needed by, the varied industries of the State.

Thus far all efforts to improve the situation and to overcome as far as practicable the evil effects of inadequate earlier legislation have failed of accomplishment. This was not because the proposed laws were necessarily unwise, but because they were misunderstood. But these efforts have had great educational value and could well serve as a basis for a proper adjustment of the matter at this time.

EARLIER EFFORTS TO IMPROVE IRRIGATION LAWS.

In 1878 the legislature of California passed the first law designed eventually to provide proper public control of the appropriation and use of water. This law created the office of state engineer for "the acquirement of data upon which the State might formulate a policy and frame legislation respecting irrigation matters." In 1880 the state engineer appointed under this act submitted strong recommendations as to revision of the water-right laws then in force, covering not only the definition of existing rights and the acquirement of new ones, but also suggesting the formation of irrigation districts along the lines subsequently put into force by the Wright Act of 1887. The principles embodied in the state engineer's recommendations as to the definition of existing water rights and the acquirement of new ones, although discarded by California, were later made the basis of the best irrigation laws now in force in this country. The office of state engineer continued in existence for a period of ten years, during which a large amount of field investigation was carried on and a number of maps and two large special reports published.[a] Due to lack of support and in spite of the large amount of work done and the definite recommendations made, the office went out of existence without leaving behind any concrete results in the shape of irrigation legislation.

[a] Irrigation Development, Wm. Ham. Hall, state engineer, 1886; Irrigation in California (southern), Wm. Ham. Hall, state engineer, 1888.

THE WATER AND FOREST ASSOCIATION BILL.

The next move to change the water-right laws of California was made in 1903, following an exhaustive examination of irrigation conditions and needs on a number of the important streams of the State, from Sweetwater River on the south to Yuba River on the north. A study of the water laws and their workings was made by the Office of Experiment Stations,[a] while the United States Geological Survey gathered data on water resources. In both of these investigations substantial assistance was rendered by the California Water and Forest Association, and at their conclusion this association appointed a commission to frame a new water law. This commission was composed of the chief justice of the California supreme court, the presidents and the professors of civil engineering of the two universities, the chief of irrigation investigations of the Department of Agriculture, the chief hydrographer of the Geological Survey, and two of the leading irrigation lawyers of the State. The bill framed, although not unanimously reported in some matters whose constitutionality was questioned, represented the mature judgment of the commission as to the needs of the State in the matter of irrigation legislation. Although radical in some of its provisions, it is the belief of many whose opinions are entitled to weight that this bill would not have disturbed any valid existing rights, yet it was met with aggressive opposition from the sections of the State in which rights to water had become most nearly settled by past litigation and the available supply was most fully appropriated. It was hoped that after this measure had been carefully studied many of its provisions to which no valid objection was urged might at least be enacted into law. Thus far, however, it has had no influence whatever on legislation.

DISCUSSION BEFORE THE COMMONWEALTH CLUB.[b]

The last attempt to improve the laws did not extend to the point of framing a bill or of urging a change before the legislature. It was rather confined to a thorough discussion before the Commonwealth Club of California of the previous attempts at legislation and of what seemed practicable in the light of previous opposition. The result of this discussion, which extended over more than a year and during which some of those who most strongly opposed the bill of the Water and Forest Association expressed a willingness to support any reasonable measure that might be proposed, was an agreement by those present that another effort to better the existing laws should be made. The plan outlined, however, was less radical than that pro-

[a] U. S. Dept. Agr., Office Expt. Stas. Bul. 100.

[b] Transactions of the Commonwealth Club of California, Vol. I, No. 6.

posed in the Water and Forest Association bill. This agreement by the Commonwealth Club was reached in 1905, but no move has been made to carry the matter any further.

RECENT LEGISLATION IN OTHER STATES.

At the time the Water and Forest Association bill was presented to the legislature but three States—Colorado, Wyoming, and Nebraska—had provided systems of public control of the acquirement and definition of water rights, or had sought by general legislation to control the distribution of water. Since then, with the exception of California, Montana, Washington, Kansas, Texas, and Arizona, all of the Western States have fallen into line with improved legislation of some kind. In the first place, with the exception of Colorado, they provide for the collection by public officials of all data necessary as a basis for the definition of existing and future rights to water. This eliminates at the start one of the evils with which California has to deal in water-right adjudications, viz, the basing of decrees almost wholly on the testimony of those claiming the water, with no regard whatever for the rights of the public to the water not yet appropriated or not being beneficially used. In their method of adjudicating rights after the collection by public officials of the data necessary on which to base them, Nebraska, Nevada, and Oregon now follow Wyoming by having adjudications made as administrative acts by State administrative boards. In Utah, North Dakota, South Dakota, Oklahoma, and New Mexico the physical data collected by the State officials is made the basis of adjudications by the courts. In the four last-named States and Territories the data are submitted to the attorney general, who brings the actions for adjudications. In Idaho physical data are collected by the State engineer, but do not form a basis for general adjudications initiated by parties claiming water rights.

In the procedure for acquiring rights to water in the first instance, 10 of the 17 Western States and Territories comprising the arid or semiarid sections now exercise complete supervision, thus doing away with the many uncertainties of the earlier plan of merely posting a notice and taking water. The essential feature of the supervision exercised requires proof to be made of actual appropriation and use and therefore eliminates from the public records filings that have no validity but which give a color of right which in truth does not exist. An eleventh State—Montana—has adopted the principle of the other States, but only applies it to appropriations from streams on which the rights have been adjudicated.

NEEDED CHANGES FOR CALIFORNIA.

It is not the purpose of this Office in this report to outline irrigation legislation for California, the belief being that this is a func-

tion properly belonging to the State government. There are several changes, however, the desirability of which has not been questioned so far as known during all the extended discussion that has taken place. These may be stated briefly as follows:

1. All claimants to water from the same sources should be made parties to any suit for the determination of water rights from that water source. The present law makes a decree binding only upon the parties to the suit and leaves the water rights open to attack in subsequent suits by other or later claimants.

2. The public should be represented at all water-right litigation and should present testimony as to the physical data involved, such as areas irrigated, duty of water, necessary allowances for seepage losses, etc. This would prevent water being decreed that could not be used beneficially and would insure the greatest possible development, it is believed.

3. All rights that have accrued by court decrees, appropriation, and use, or by prescription, should be defined and listed, in order to give stability to existing rights and to enable unappropriated water to be utilized without danger of attack in the future.

4. Proof should be required of future appropriations and they should be listed according to streams in such a way and in such place or places that they would be accessible for reference.

5. Provision should be made for eliminating from the operation of any law regarding the definition and listing of existing rights any streams on which the rights of all claimants therefrom have already been settled by litigation, and on which there is no question of nonbeneficial use of water already appropriated, except that such streams should be included on request of the irrigators therefrom.

6. Provision should be made for the distribution of water under public authority in accordance with established rights, at least when desired by a reasonable number of the appropriators from a given stream.

Much difference of opinion exists as to the best method of making these or any changes, coming as they do so late in the irrigation development of the State. It is believed, however, by those interested in remedying conditions that while it can not be hoped to get an ideal law, yet conditions could be measurably improved without disturbing vested rights.

THE PRESENT NEED FOR ACTION.

The efforts to enact better laws regarding the acquirement and protection of water titles above outlined received the mature and very careful consideration of some of the best minds in California. That nothing beyond investigation, recommendation, and discussion has resulted is due to the fact that both public and private

interests of great importance are involved and must be fully and fairly considered before any adequate progressive policy can be put into effect.

It is the belief of some of those prominent in former discussions of the subject that a reasonable and fair revision of the water-right laws of California could be accomplished if properly undertaken. They also believe that a commission should be appointed under authority of the legislature to investigate and consider thoroughly the entire question and present such recommendations to a succeeding legislature as seem desirable and necessary. Whatever is done should be done with the sole purpose of bringing about the largest measure of improvement consistent with the obligation of the State to protect fully the rights that have become vested under the procedure previously provided, and it is believed that a commission appointed with such an end in view could accomplish results whose benefits would extend to every irrigated acre in the State and quicken the development of irrigation on some streams to a degree almost immeasurable at this time. Such a commission, for instance, might make trial determinations of existing vested rights on one or two important typical streams, taking testimony to establish dates of appropriation and amounts of actual use, and making field surveys and studies to show the areas now irrigated and the fair and reasonable water requirements of crops under conditions present. The procedure shown to be desirable for defining existing rights and for acquiring new rights on such typical stream or streams would certainly be strong evidence of the real needs of water-right procedure throughout the State. It is believed that it would also convince those who have heretofore honestly opposed water-right legislation in California that such legislation as is suggested herein would not only in no way disturb any rights that have been fairly acquired, but that such legislation would give a degree of certainty and stability to existing rights not possible under present practice.

DUTY OF WATER DETERMINATIONS.

The first determinations of duty of water by this Office in California were made on Gage Canal, at Riverside, in 1889. From this beginning gross or net determinations have now covered a total of 118,000 acres, not counting records of use on many thousands of acres furnished by canal companies and fully or partially checked by this Office. Nearly all of the principal irrigated crops of the State have been considered to a greater or less extent. In addition, tank experiments have been conducted to learn more of the exact water requirements of crops than is possible under the usual field conditions, and since 1908 experiments to determine the relative effects of different quantities of water applied to alfalfa have been made on 20 acres on

the university farm at Davis. Taken as a whole, there can be no question that, chiefly by calling attention to wasteful use, these determinations have increased the duty of water in California by a large percentage.

In a State so large as California and with as many conditions of soil, drainage, climate, and topography, duty of water determinations in one section may have only general value elsewhere. Again, the amount used may represent what is available rather than the amount required Where the supply is scarce the "duty" may merely be the least that can be applied at one irrigation multiplied by the number of times which it is possible to irrigate; where it is ample, it may be, and often is, many times the real needs of the plants. Outside of experimental data the best guide is the practice in localities in which water is necessary and too valuable to waste; but owing to the desirability of demonstrating extravagant use in certain localities, all of the duty of water determinations mentioned in the succeeding pages were not made in such localities.

ALFALFA.

Miscellaneous measurements.—The most data collected have referred to alfalfa, measurements having been made on 7,202 acres, not including the experiments at Davis. A summary of these measurements follows:

Summary of measurements of duty of water on alfalfa, 1899–1910.

Location.	Source of water supply.	Year.	Acreage.	Depth of water applied.
				Feet.
Turlock	Turlock Canal, average 10 farms	1909	909	3.76
Modesto	Modesto Canal, average 7 farms	1910	521	1.90
Fresno	G. W. Uridge farm, pump	1910	60	5.10
Madera	O. L. Sayre farm, pump	1910	500	4.74
Turlock	Turlock Canal	1904	2,625	7.69
Modesto	Modesto Canal	1904	626	5.76
Do	Modesto Canal, Perley ditch	1909	275	8.60
Do	Modesto Canal	1909	80	1.80
Turlock	Turlock Canal, Hickman	1909	909	4.70
Pomona	Pumping, 8 farms	1905	192	1.40
Do	Pumping, 7 farms	1905	287	2.30
Do	Pumping, 6 farms	1908	218	2.40
Total and average			7,202	4.18

The largest amount found to have been used was a depth over the surface of 8.60 feet on 275 acres under the Perley ditch at Modesto. This land was largely newly seeded. On another small tract of 80 acres under the same ditch a duty of 1.80 feet in depth was found. The highest duty found was a depth of 1.40 feet, which was the average of measurements made on 8 farms at Pomona by Mr. C. E. Tait. The highest duty found in San Joaquin Valley over a considerable area was a depth of 1.90 feet, which was the average of measurements

made by Mr. R. D. Robertson on 7 farms near Modesto, covering 521 acres. The average depth found on the entire 7,202 acres was 4.18 feet, but as this included measurements made at the heads of ditches as well as at the points of use, thus including some seepage losses, and as they also included both wasteful and economical use, it is not a true indication of the water requirements of this crop in California. It is believed that an average of the amounts used on the 17 farms in Modesto and Turlock districts covered by measurements in 1909 and 1910, viz, a depth of 2.83 feet, more nearly represents reasonable use in such localities as San Joaquin Valley, and that an average of the measurements on the 21 farms at Pomona, viz, a depth of 2.03 feet, fairly represents the best practice in southern California.

Experiments at Davis.—Thirty plats were used in the experiments at Davis in 1910 on the duty of water on alfalfa and on the frequency and amounts of irrigations. Four of these plats were seeded in 1908 and the remainder in 1909. As the experiments of 1909 left the plats quite unequal at the end of the season, an effort was made by reseeding and disking to give them an equal start in 1910.

Of the 30 plats, 8 received no water in 1910. Six cuttings gave an average yield of 4.08 tons per acre.

Two plats received a depth of 24 inches and yielded 6.43 tons per acre as the total of six cuttings. This shows an increase of 1.64 tons over the yield of 4.79 tons on the plats receiving but 12 inches.

Twelve plats were given a total seasonal depth of 30 inches and yielded an average of 8.09 tons per acre.

On three plats the depth of water applied was 36 inches and an average yield of 7.60 tons was produced, which is 0.49 ton less than the yield from the plats receiving 30 inches of water.

The last three plats, which received 48 inches, yielded 8.45 tons per acre.

While the results as stated show a substantial increase in yield with the increased water applied up to 30 inches, above that amount the increase was not in proportion to the water applied. This is not, however, conclusive that 30 inches is all of the water that should be applied to alfalfa, but that such an amount will produce very satisfactory results. Further experiments will be made as to the effects of larger quantities.

GRAIN.

With the idea that grain will form an important crop in rotation when the great valley lands of California come more fully under irrigation, experiments in the irrigation of this crop were begun by this Office at Davis in the spring of 1910. The results of these experiments should be of interest to those farmers who can but do not now irrigate their grain.

Three half-acre plats were seeded to barley March 12. Of these, one was irrigated twice, with a total depth of 5.2 inches; one was irrigated once, with a depth of 3.6 inches, and the other received no water.

The plat that received no water yielded 1.56 tons of hay and 1,160 pounds of grain per acre.

The plat that received one irrigation yielded 1.72 tons of hay and 1,480 pounds of grain per acre, an increase in the yield of grain of 27.5 per cent.

The plat that received two irrigations yielded 2.23 tons of hay and 1,840 pounds of grain per acre, an increase in grain over the unirrigated plat of 58.5 per cent.

It is the intention of the Office of Experiment Stations to continue experiments in grain irrigation at Davis with the hope of encouraging those who are farming small areas at least to use water on grain whenever they can get it.

CORN.

Experiments in irrigating corn were made at Davis in 1910. Egyptian corn and Indian corn were watered by the furrow method, and in both cases very large increases in yield were obtained with relatively small amounts of water.

Five separate plats of Egyptian corn were grown, of which 1 received no water, 2 received one irrigation each, and 2 received two irrigations each.

One of the plats that received only a single irrigation of 3.75 acre-inches per acre gave a yield of unthrashed heads 90 per cent greater than the plat that received no water. The other was given a depth of but 3.10 inches and gave 117 per cent increase in yield. Of these 2 plats, the former was irrigated June 24, the latter three weeks later.

Of the plats that received two irrigations, 2 gave increased yields of 125 per cent and 2 gave increased yields of 174 per cent. The former received a total depth of but 5.5 inches, the irrigations being given June 24 and July 13. The other two received practically the same amounts of water, but the first irrigation was nearly a month earlier, when there was apparently a greater need of water.

The Indian corn included in the experiment was in four plats, receiving no water, a depth of 3.3 inches in one irrigation, 5.3 inches in two irrigations, and 8 inches in three irrigations, respectively.

The plats receiving no water gave a yield of green fodder of 7.15 tons per acre. Need for water was plainly evident June 27.

Where one irrigation of 3.3 inches was given, the increase in yield was 23.2 per cent.

With two irrigations, having a total depth of 5.3 inches, the increase was 30.7 per cent.

With a depth of 8 inches in three irrigations, the increase was 47.1 per cent.

Deciduous fruits.—Measurements of the duty of water on citrus fruits covering 7,500 acres in Santa Clara Valley, made in 1904, showed an average depth applied of 1.95 feet. Records of the Irrigation Co. of Pomona from 1906 to 1909, as given in a manuscript report of Mr. C. E. Tait, show a depth of 0.45 foot applied to 2,500 acres.

Vineyards.—As a rule, vineyards are not irrigated in California. Measurements have, however, been made on a few vineyards, showing an average depth applied of 0.43 foot with one irrigation and of 0.86 foot with two irrigations.

With the assistance of Mr. Frank T. Swett, a vineyardist of Martinez, this Office is now conducting a study of the desirability of irrigating grapes in this State.

Citrus fruits.—The duty of water on citrus fruits in California may be considered fairly well established. Measurements made by this Office to determine it, together with data compiled from irrigators' records, the whole covering the period 1899 to 1909, follow below. Other than to call attention to the very high duty attained at Pomona, no comment on these results seems necessary. Expressed according to area irrigated per unit of flow of water, the duty of citrus orchards at Pomona is figured as 1 miner's inch under a 4-inch pressure to each 8 acres irrigated. In the section around Riverside, the duty is considered as 1 inch to 5 acres, but the rainfall at Pomona is considerably more than it is at Riverside. This duty of 1 inch to 8 acres is probably the highest duty to be found in this country.

Summary of measurements of duty of water on citrus fruits, 1899–1909.

Location.	Source of water supply.	Year.	Acreage.	Depth of water applied.
				Feet.
Riverside	Gage Canal, District No. 1	1899	3,959.0	2.32
Do	Gage Canal, District No. 2	1899	2,871.0	2.23
Do	Gage Canal, District No. 3	1899	530.0	1.78
Do	Gage Canal, District No. 1	1900	3,614.0	2.43
Do	Gage Canal, District No. 2	1900	3,237.0	2.12
Do	Gage Canal, District No. 3	1900	650.0	1.63
Do	Gage Canal, District No. 1	1901	3,614.0	2.07
Do	Gage Canal, District No. 2	1901	3,237.0	2.03
Do	Gage Canal, District No. 3	1901	650.0	1.39
Do	Gage Canal, 5 farms	1901	108.3	2.00
Do	Riverside Water Co	1901–1908	9,000.0	[a]2.29
Porterville	Lindsay Water Development Co	1900	280.0	1.50
Do	....do	1901	267.0	1.14
Do	Pioneer Canal	1901	228.0	1.41
Do	Pleasant Valley Canal, Spratt farm	1901	38.0	1.55
Pomona	Wells, 12 farms	1905	318.5	.80
Do	Del Monte Irrigation Co	1906–1909	2,000.0	.82
Do	Palomares Irrigation Co	1906–1909	600.0	.80
Total and average			35,201.8	1.68

[a] Includes 3,000 acres of alfalfa.

Segregating the figures given in the above summary by districts, the average for Riverside is 2.03 feet, for Porterville 1.40 feet, and for Pomona 0.81 foot. It might be added that the average annual rainfall at Riverside is 0.83 foot, at Porterville 0.70 foot, and at Pomona 1.65 feet.

MISCELLANEOUS CROPS.

In addition to the measurements given above, data have been gathered showing the amount of water used where a number of crops have been included, rather than only one, as heretofore. These are collected in the following self-explanatory table:

Summary of data regarding the duty of water on miscellaneous crops.

Location.	Source of water supply.	Year.	Acreage.[a]	Depth of water applied.	Crops.
				Feet.	
Riverside	Gage Canal	1899–1905	80,667	2.25	Citrus fruits and alfalfa.
Do	Riverside Water Co				
Porterville	Poplar Ditch	1901	4,260	3.19	Orchard and alfalfa.
Do	Pioneer Ditch				
Do	Pleasant Valley Ditch	1901	1,000	7.23	Alfalfa, fruit, and vegetables.
Do	Plano Ditch				
Do	South Tule Independent				
Imperial Valley	Imperial Co.'s Nos. 1, 4, 5, and 7.	1905	120,000	2.04	Alfalfa, grain, and cantaloups.
Turlock	Turlock Canal	1909	52,900	4.50	Mostly alfalfa.
Modesto	Modesto Canal	1909	22,136	6.90	Do.
Total and average			280,963	4.35	

[a] Where the same acreage has been covered by measurements for several years, the acreage is repeated for each year.

In 1908, through the courtesy of Miller & Lux, an agent of this Office copied the records of water delivery by San Joaquin and Kings River Canal and Irrigation Co., July 1, 1906, to June 30, 1908. This company covers a large acreage in Fresno, Merced, and Stanislaus Counties on the west side of San Joaquin River. The area to which water was delivered in 1906–7 was substantially 75,000 acres and in 1907–8 substantially 91,000 acres. The depths applied, in feet, to the various crops grown were as follows:

July 1, 1906, to June 30, 1907: Alfalfa, 1.89; grain, 0.74; corn, 2.13; orchard, 2.64; vineyard, 2.32; potatoes, 1.00; garden, 2.44; grass, 1.23.

July 1, 1907, to June 30, 1908: Alfalfa, 2.23; grain, 0.84; corn, 1.65; sorghum, 1.02; orchard, 2.45; potatoes, 2.49; garden, 2.91; grass, 0.60.

TANK EXPERIMENTS.

The tank experiments to determine something of the water requirements of wheat and barley were made, chiefly at Tulare, from 1903 to 1905. These experiments were a part of an extensive series of tank experiments to ascertain the amount and character of evapora-

tion losses from soil surfaces.[a] In an experiment with wheat, in which the maximum amount of water applied was 24 inches in depth, the yield increased with the quantity of water applied. In another in which the maximum application was 27 inches, the maximum yield was obtained with 18 inches. In the first experiment with barley, the tanks received 7, 12, 15, 20, and 24 inches in depth, and with one exception the yields increased with the increase of water. In the second experiment the maximum application was 27 inches and, as in the case with the second wheat experiment, the maximum yield was obtained with 18 inches. In these experiments no water could escape by percolation. It was the conclusion from these experiments that with the usual percolation in field practice, the best results would be obtained with wheat and barley in the vicinity of Tulare by the use of depths of 18 to 24 inches of irrigation water. Investigations since made in the grain districts outside of California show[b] that an average depth of 2 feet will about represent the amount applied to grain crops in the cooler climates. Experiments with barley at Davis in 1910 gave an increased yield of 58.5 per cent by the use of but 5.2 inches of irrigation water.

INVESTIGATIONS OF IRRIGATION BY PUMPING.

A few years ago it was usual to consider only the flow of streams in estimating the water supply available for irrigation. Conditions have entirely changed and to-day it is estimated that there are 10,000 to 20,000 pumping plants supplying water to crops in this State. Within a radius of 10 miles about Pomona 200 such plants are now in operation, representing a cost of installation of at least $1,000,000.

MECHANICAL TESTS OF PUMPING PLANTS.

Since 1904 this Office has given much attention to the study of pumping for irrigation. In that year mechanical field tests were made of 19 plants in different parts of this State, with a view primarily of ascertaining their efficiency and the cost of pumping for irrigation. The plants tested included both centrifugal and plunger pumps, which were operated by gasoline engines, electric motors, and steam engines. The average combined efficiency of engine and pumps was found to be 46.1 per cent, the highest being 65 per cent and the lowest 26 per cent. It was not possible to determine positively from these tests whether the great variation in efficiency was due to arrangement of machinery, to neglect, to improper speed of pump, or to the type of pump used, but the report of Prof. J. N.

[a] U. S. Dept. Agr., Office Expt. Stas. Bul. 177.

[b] U. S. Dept. Agr., Farmers' Bul. 399.

Le Conte,[a] who made the tests, called attention to the following facts: (1) The larger the plant the more efficiently it will perform, this being true of both engine and pump; (2) an engine or pump too large for its work is running uneconomically; (3) there should be the most direct possible transmission between engine and pump; (4) suction and discharge pipes should be large and have the fewest possible number of bends; (5) more expense is incurred by neglect of care, cleanliness, and intelligence in operation than all others combined. Prof. Le Conte accompanied his report with diagrams intended to help prospective irrigators in estimating the cost of installations.

In addition to the field tests, Prof. Le Conte made seven laboratory tests of pumps during the same year. These were all made under exactly the same conditions and were intended to show the effect of variation of speed or head on pump efficiency, and also the relative efficiencies of several different makes of pumps. It was shown by the tests, among other things, that for every speed there is a definite head at which a pump works best, and, conversely, that for a given head there is a definite speed required for most efficiency.

In 1905 the investigations begun the previous season were continued at Pomona and Riverside and on the lower Sacramento River, the work being done by Prof. J. N. Le Conte and Mr. C. E. Tait.[b] Complete tests were made of 38 plants and fuel and water tests were made of 100 others immediately about Pomona. It was found from the complete tests, among other things, that for gasoline-driven plants the efficiency should vary from 30 per cent for the smaller plants to about 50 per cent for the larger plants. For electrically driven plants the variation should be from at least 40 per cent for a pump of 5 useful water horsepower capacity to about 55 per cent for a pump with a capacity of 40 useful water horsepower. Where centrifugal pumps are used, the plant efficiency of steam-driven plants did not differ definitely from that of the plants driven by gasoline or electricity, although the report of Prof. Le Conte and Mr. Tait states that, as a rule, the plant efficiency for the electric pump is definitely higher than for a corresponding plant operated by gasoline. As for the relative values of the different types of pumps, the report states that the plant efficiency in deep-well pumps in general may probably be expected to surpass the efficiency of centrifugal pumps, although the tests made were considered insufficient to prove the general law. With electricity as the motive power and as compared with centrifugal pumps, one test showed the screw pump to be less efficient, two tests showed the deep-well pumps to have about an equal efficiency, and three tests showed the triplex and rotary pumps to have

[a] U. S. Dept. Agr., Office Expt. Stas. Bul. 158.

[b] U. S. Dept. Agr., Office Expt. Stas. Bul. 181.

somewhat higher efficiencies, but no conclusive statements were attempted on the basis of so few tests. With steam as the motive power the plant efficiency of the plunger pumps was found to be much higher than for any other type, while for the air-lift plants it was very much lower.

The partial fuel and water tests of the hundred plants around Pomona also brought out very interesting data. Platting the amount of fuel used by the different classes of plants—gasoline, electric, and steam—Mr. Tait found, first, that the larger plants showed a greater economy in fuel consumption than the smaller plants, and, second, a striking variation in fuel consumption in the different plants. In the case of the gasoline plants, some were found to be using double the quantity of gasoline per useful water horsepower hour consumed by the most efficient plants. He found, for instance, that 68 plants consumed 38,000 gallons more gasoline during 1905 than would have been required with economies that were possibly attainable with proper design and installation. Furthermore, he found that there would have been an additional saving with fewer small plants and more large ones, such as might be obtained by more extensive cooperation in the installation of pumping plants.

It is safe to say that the investigations summarized above have resulted in the saving of thousands of dollars to those deriving their water supply from pumping. The full reports have been extensively circulated and have created an interest in better plants among both irrigators and pump manufacturers that could not have been aroused so effectively in any other way. The need is for further work along the same line and along the line of practical suggestions to irrigators regarding the best method of sinking wells, the best types of pumping machinery, and the best method of installing and operating pumping plants to secure the highest possible efficiency and thereby eliminate the heavy operating losses still incurred on many plants.

PUMPING FOR IRRIGATION AROUND POMONA.

To meet the present need in the matter of practical information about pumping, an investigation has been made by Mr. C. E. Tait, irrigation engineer in charge of the work of this Office in southern California, of the use of underground water pumped for irrigation at Pomona, Cal. A careful examination of several hundred pumping plants in the vicinity of Pomona has disclosed the fact that the average cost of pumping by the company systems in that vicinity is about 2.5 cents per inch per hour, which is the equivalent of $15 per acre-foot. Adding interest on water-right investment, the average cost of water delivered from company systems is $18 per acre per annum, or about $22 when cover crops are raised. This high cost of water would not be justified with any crops much less profitable than those grown

about Pomona. Under the private pumping plants the annual cost is about $2 higher. For citrus fruits it is now found profitable to raise water as much as 400 feet, and a 100-foot lift, when necessary, is considered justified for alfalfa, even when it costs an average of $19.20 per acre per annum. In addition to cost data, Mr. Tait gives thorough descriptions of the organizations for pumping and delivering water about Pomona, pumping installations, methods of water distribution, methods of irrigation, and duty of water, and calls attention to the necessity for great economy in the development and use of the very valuable water supply of the southern coastal valleys.

STUDIES OF WATER DISTRIBUTION AND DELIVERY.

No subject with which irrigation companies and associations have to deal is more perplexing than that of water distribution and delivery. Frequently its importance is not appreciated, resulting in much unpleasantness between irrigators and those responsible for water delivery. Many irrigation systems have been planned by engineers unfamiliar with the necessities of irrigation practice, and it is therefore to be expected that the importance of water delivery has not been appreciated.

THE BUSINESS SIDE OF WATER DELIVERY.

For the purpose of creating a greater interest in this subject on the part of irrigation managers in California and also of making available for their use information as to the details of water delivery, the preparation of a bulletin on this subject was undertaken in 1906. Later, a number of irrigation enterprises outside of California were included in the field of investigation. The report was completed early in 1909, but has only recently been issued. Perhaps the most important matters dealt with in this report have to do with the value of measuring the water delivered to irrigators and of keeping records of the amount of water used. Of the 40 or more enterprises whose delivery systems are described, water is measured and a record of its use kept on practically all of those under which water has a high value. Especially is this true under the best managed systems of southern California.

The business side of water distribution is not, however, its only side. How to construct farm laterals, how to make headgates, what kind or kinds of measuring devices to use, the value of underground distributaries, and the use of concrete in irrigation structures are all matters that demand attention and have been considered by this Office during the past 10 years. How to construct farm laterals is described in detail in a previous bulletin of this Office.[a] How to make farm headgates is also taken up in these bulletins. What kind or kinds

[a] See especially U. S. Dept. Agr., Office Expt. Stas. Bul. 145 and Farmers' Bul. 263.

of measuring devices to use is briefly discussed in the bulletin on water delivery already mentioned, but a more complete treatment will be prepared for the particular benefit of irrigators in California, on the completion of the installation of examples of standard irrigation measuring devices at the university farm at Davis, mentioned later in this report.

THE USE OF CONCRETE IN IRRIGATION.

Another study of perhaps equal importance with any other which this Office has undertaken in connection with water distribution is one made on the use of concrete in irrigation structures, by Prof. B. A. Etcheverry, of the department of irrigation of the University of California. He has based his study largely upon the irrigation practice in southern California and gone very carefully into the subject of the construction and use of underground concrete distributaries so extensively employed in that section. The steady increase in the value of water in some sections of the State is causing farmers to make many inquiries about lining canals with concrete and the use of underground concrete pipes, and Mr. Etcheverry has made a study of the cost of employing this material. The cement pipe used so extensively in southern California is generally the beveled lap-joint pipe made in sections 2 feet long. It is frequently made by irrigators themselves by the use of special tools manufactured for the purpose. The cost of making and laying this pipe was found by Mr. Etcheverry to vary from about 11.5 cents per foot for 6-inch pipe to about 30 cents per foot for 12-inch pipe and about $1.20 per foot for 36-inch pipe. He has also studied the methods and the cost of making complete installations of concrete-pipe underground distribution systems, including turn-outs, measuring devices, and accessories; lining of canals with cement and concrete; reenforced-concrete pressure pipes, conduits, siphons, and flumes for both large and small installations; concrete headworks, wasteways, reservoirs, and other large structures used in the conveyance and distribution of irrigation water.

THE PREPARATION OF LAND FOR IRRIGATION.

In 1904 this Office, in cooperation with the State of California, issued a bulletin, particularly for the new settler, entitled "Preparing Land for Irrigation and Methods of Applying Water."[a] This bulletin is now out of print, but much of the matter contained in it has been reprinted in Farmers' Bulletin No. 263, entitled "Practical Information for Beginners in Irrigation." The practice of preparing land for irrigation varies considerably in the different parts of California, but there has been a noticeable improvement during the past 10 years, particularly in the sections in which this Office has been making

[a] U. S. Dept. Agr., Office Expt. Stas. Bul. 145.

investigations. Especially is this true in the character of the levees built for the different forms of check irrigation. This Office has lost no opportunity to impress on irrigators the advantages of making levees as low as possible, not only because of the smaller cost and greater convenience in farm operations of such levees, but also on account of the poor condition in which the scraping for large levees leaves the surface soil. It has also constantly urged upon farmers the great advantage of the border form of checking land for irrigating alfalfa when conditions will permit of its use, this advantage lying in the low cost of preparing the land and the greater adaptability to crop rotation.

In connection with studies of the best methods of preparing land for irrigation, about 20 acres on the University farm, at Davis, were prepared for the irrigation of alfalfa by the four standard methods used for that crop—rectangular checks, contour checks, border checks, and field laterals. Each method has particular conditions to which it is adapted, and this demonstration, which has been conducted in cooperation with the University of California, has been of much help in enabling visiting farmers to decide on the best method to choose. Many irrigators have called for assistance in laying out their fields, either by surveys, when practicable, or by indicating the best method on contour maps furnished by the irrigators.

THE APPLICATION OF WATER TO CROPS.

In the study of the application of water to crops, the initial work consisted mainly in gathering data on the duty of water and the exact amount applied by individual irrigators and water companies throughout the State, all of which is covered in the summary of duty of water determinations. Later investigations have turned more toward the methods of applying water to the soil and the proper time to irrigate.

ALFALFA.

Throughout California, except in the more remote small mountain meadows, water is applied to alfalfa by some form of the check method. The different forms of this method have already been touched on in connection with the preparation of land. The two common methods of irrigating alfalfa used elsewhere, but practically unknown in the irrigation practice of this State, are the "mountain method" of flooding from field laterals and the furrow method. The former method is adapted to the steeper slopes, although used almost exclusively on all classes of land in some sections of the Rocky Mountains. In order to show the advantages of this method on land too steep to check, a small plat has just been prepared on the experimental plat at Davis on which it will be used. Aside from this, and the experiments with the three forms of check already outlined, this

Office has endeavored during the past two seasons to learn the best time to irrigate young alfalfa, and also something of the effect of varying the time of applying water and the amounts applied at each irrigation.

Irrigation of young alfalfa.—Twenty-six plats seeded to alfalfa March 18, 1909, were used in 1909 in noting the effects of varying the time of irrigation of, and the amount of water applied to, young alfalfa.

Twelve plats were watered only once during the season—five June 5, six August 10, and one September 9.

The plats irrigated June 5 gave a very light yield. The alfalfa made practically no growth after June 21, and at the end of the season at least one-half was dead.

On the plats irrigated August 10 there was practically no growth between the first cutting June 21 and the irrigation August 10. After this irrigation one good crop was cut and at the end of the season the plants were healthy and the stand was fairly good.

While the plats irrigated August 10 gave a better yield and showed a more healthy growth than the plats irrigated June 5, the plat that was not irrigated until September 9 was at the end of the season in still better condition.

On the plats given two irrigations the comparison was between plats watered early in the season and in the middle of the season, on the one hand, and plats irrigated in the middle of the season and late in the season on the other.

In the first instance water was applied May 31 and August 10. Three light cuttings were harvested, but the growth was very small between the cutting June 21 and the second irrigation August 10.

In the second instance water was applied August 1 and September 9. With considerably less water than was used in the first instance, the yield and condition at the end of the season were both much better. This was also true in comparison with a third group of plats on which both irrigations were given in the middle of the season.

The last group of plats were given three irrigations—May 29, July 13, and August 23, in each case being at intervals of about 6 weeks. They gave a fully developed stand with a good yield the last two cuttings. At the end of the season these plats presented the best appearance of any plats in the field.

As a partial check against the results of 1909 three checks were seeded to alfalfa in March, 1910, and irrigated early, in the middle of the season, and late in the season, respectively, that is, June 3, July 11, and August 12. As in 1909 the plat that gave the best growth to carry over into next season was the one that received the late irrigation on August 12. The alfalfa on the plat that was irrigated early,

that is, June 3, would have been entirely lost by the end of the season if a second irrigation had not been given early in August.

The conclusion, plain from these experiments, is that young alfalfa should not be irrigated until the roots have had a chance to penetrate beyond the dry surface layer of the soil, at least provided no water is available for late irrigation. In other words, when the available water supply for late irrigation is limited, the young plant should make the largest possible growth before receiving any water.

Variation in frequency and amounts of application.—The experiments covering these points are interesting but not conclusive.

Water was applied before cuttings, after cuttings, and both before and after cuttings.

When applied before cuttings the depths given at the irrigations were 6, 7½, 8, 9, and 12 inches, respectively. On three plats receiving 24 inches in depth, instead of giving three 8-inch irrigations, the first irrigation was 12 inches, and the two subsequent irrigations 6 inches each. Where 36 inches was applied, some received four 9-inch waterings and some received 12 inches first and later three 8-inch waterings. In none of these cases did this variation either increase or decrease the yields. If heavy spring irrigations, when water is usually plentiful, followed by lighter irrigations in the summer, will give the same yield as uniform irrigations throughout the season, the farmer who can not get late water need not feel discouraged. The experiments of next season will help to elucidate this.

The remaining interesting point of comparison in these experiments of 1910 is in reference to the time of irrigation and the cuttings. As stated, water was applied in some cases before cuttings, in some cases after cuttings, and in other cases before and after cuttings. Where applied before cuttings or after cuttings the depth of irrigation was 7½ inches. Where applied both before and after, it was 3¾ inches. In each of the three instances the total quantity applied during the season was 30 inches. The interesting result was that practically the same yield of 7.6 tons per acre was taken from all of the plats. This, too, will be a question to check by later experiments.

SUGAR BEETS.

Investigations of the application of water to sugar beets made in California were but a part of a general study of the irrigation of this crop throughout the West. The results of these investigations are given in a recent Farmers' Bulletin,[a] prepared by Mr. F. W. Roeding and issued in April, 1910. Mr. Roeding discusses in this bulletin, among other questions relating to the irrigation of sugar beets, the

[a] U. S. Dept. Agr., Farmers' Bul. 392.

following: Soil and climate suited to growing sugar beets; preparation of land and methods and time of irrigation; beet culture under irrigation; crop rotation and fertilizing; and results of experiments under irrigation. He found that furrow irrigation of sugar beets is decidedly better than flooding, especially when the water is distributed to the furrows through lath boxes or pipes set in the ditch banks. This method permits of deep irrigation, prevents waste, and keeps the water from coming in direct contact with the plant at the surface of the ground. Mr. Roeding called attention to the fact that the United States consumes more than one-fifth of the entire sugar production of the world, but raises and manufactures only about 25 per cent of the amount consumed here. The area devoted to this crop in California is capable of being greatly increased.

ORCHARDS.

In the investigations of the application of water to crops, the most attention has been given to orchard irrigation. In a report issued by this Office in 1902 [a] Prof. E. J. Wickson, now director of the California Agricultural Experiment Station, called attention to the advantages of the check method of orchard irrigation then coming into use. Later bulletins [b] have given the results of investigations, chiefly at Pomona and Riverside, to determine the relative advantages and disadvantages of deep and shallow furrows in applying water. A still later bulletin,[c] prepared by Dr. S. Fortier largely from data gathered by this Office in California, deals quite fully, not only with the application of water to orchards, but also with all important matters pertaining to the growing of orchards under irrigation. Still further consideration was given to this important subject in the investigation on irrigation by pumping at Pomona, by Mr. C. E. Tait, already referred to.

The usual method of irrigating orchards is by means of furrows, but practice in the manner of making them varies considerably in the different parts of the State. Formerly the usual plan in the citrus-orchard sections was to make from 6 to 12 shallow furrows between each row of trees, but now, two deep furrows, 8 or 9 inches deep and run as close to the tree limbs as can conveniently be done, are found preferable when lateral percolation is not too slow. Where two such furrows are not sufficient four usually will be. In his report on practice around Pomona, Mr. Tait shows that the basin method of flooding has been practically abandoned in favor of the

[a] U. S. Dept. Agr., Office Expt. Stats. Bul. 108.
[b] U. S. Dept. Agr., Office Expt. Stas. Buls. 177 and 203.
[c] U. S. Dept. Agr., Farmers' Bul. 404.

furrow method in the citrus districts of the South, owing to the much greater evaporation losses and the baking of the soil surface with the basin method. In that section a number of forms of zigzag or cross furrows have been adopted to give more equal distribution of the water, especially when slopes are considerable.

In the experiments at Pomona and Riverside, already alluded to, the advantages of deep over shallow furrows were strongly demonstrated. Briefly, some of the conclusions arrived at from the many experiments made were as follows:

(1) The evaporation losses from plowed but uncropped soils in the warmer valleys of California may exceed nine-tenths of the water applied to the surface in small amounts and at frequent intervals, and without being followed by thorough cultivation.

(2) The greatest losses occur by evaporation immediately after irrigation and before the land can be cultivated.

(3) By preventing surface wetting, deep irrigating furrows result in much less loss by evaporation than shallow furrows.

(4) Evaporation losses from cultivated soil were found to be as much as from 50 to 75 per cent less than the losses from uncultivated soil.

(5) Shallow mulches have little effect in checking transpiration of moisture from the soil, while mulches 6 to 9 inches are quite effective.

SEEPAGE LOSSES FROM CANALS.

Seepage from canals and ditches constitutes some of the most serious losses in irrigation, and taken in connection with waste and evaporation losses in application, reduce on the average by from one-fourth to one-third the area that might be irrigated by the water now used. So serious are these losses that hundreds of thousands of dollars are being expended each year to prevent them. This Office has done everything possible within its means to assist in locating seepage losses and to disseminate information as to the best practice in stopping them.

The first means of preventing seepage losses from canals was by paving with river bowlders, later set in lime and cement mortar. At present the chief lining used is cement or concrete, the former 1 inch or less in thickness, the latter from 2 to 6 inches. Clay puddle is an old form of prevention, and is still used to some extent where the proper material is available. Crude oil with a large percentage of asphaltum has been used on several canals and reservoirs in this State, but with little permanent success.

In 1906 experiments were made at Modesto looking to the finding of some suitable lining for small farm ditches other than clay

or cement, this work being done by Prof. B. A. Etcheverry, with some assistance from this Office.[a] The various linings tried were heavy oil, heavy oil and gravel, thin oil, clay puddle, cement motar, cement concrete, cement-lime concrete. Cement concrete 3 inches thick was found to stop 86 per cent of the loss in an unlined ditch and heavy oil 50 per cent. Later experiments by this Office on the University farm, at Davis, also later experience on the canals lined with oil, do not bear out the first conclusions regarding the value of the latter material. While it is effective in preventing some seepage as long as it lasts, and will reduce erosion, it will not prevent the growth of weeds for more than one or two seasons. The other materials experimented with at Davis, besides oil and cement concrete, were lime concrete, brick and asphalt, clay puddle, alkali puddle, cement plaster, and burlap and oil. The results were unsatisfactory, from a practical standpoint, for any materials other than the different forms of cement and concrete and clay puddle; they can not, however, hardly be considered as wholly conclusive that a way can not eventually be found to make these materials satisfactory.

In addition to the above experimental work, this Office has made many measurements to determine the extent of seepage losses from canals—at Imperial, Porterville, Fresno, Los Banos, Turlock, Modesto, and Woodland. These are summarized in the table below. While numerous factors determine the extent of seepage losses from canals, none approach in importance the character of the soil through which the canals pass, and nearly all efforts thus far made to stop seepage have been directed toward rendering the sides and bottoms of canals less pervious. It is known, however, that the percentage of loss is less in large canals than in small ones, and recent investigations and experiments in San Joaquin Valley by Mr. V. M. Cone of this Office indicate that both velocity and head are considerable factors. Numerous experiments in tanks at Davis have sustained the obvious fact that, other things being equal, more water will seep through a pervious substance under high head than under low head, but the measurements on Modesto and Turlock Canals in 1909 and 1910 showed a decrease in seepage losses from depths of about 1 foot up to 2 to 3 feet, followed by an increase with greater depths, and thus far this can only be accounted for by velocity. The experiments made under laboratory conditions to check these results have not yet been finally worked over by Mr. Cone, but they seem to bear out the conclusions arrived at from the field measurements mentioned.

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[a] California Sta. Bul. 188.

Summary of seepage measurements in California.

Years.	Canals.	Source of location.	Length of section measured.	Flow in canal.	Average loss per mile.
			Miles.	*Cu. ft. per sec.*	*Per cent.*
1901	Collison	Tule River	2.5	55	5.20
1901	Tipton	do		75–48	6.80
1901	Fine	do	1.5	21–32	13.70
1901	Vandalia	do		10–16	51.50
1901	Porter Slough	do		3–97	6.20
1901	Poplar	do		22–73	6.00
1901	Plano	do	2.5	7	16.00
1901	Pioneer	do		25–45	1.50
1901	Pleasant Valley	do		5–7	9.90
1901	S. Tule Independent	do		6–8	2.70
1903	Birch Lateral	Imperial Canal	3.0–4.0	18–25	1.10
1903	Beach Lateral	do	6.5	7	5.90
1903	Dahlia Lateral	do	9.5	45	2.10
1903	Dogwood Lateral	do	6.0	23	4.20
1903	Holt Lateral	do	3.0–5.0	13–27	2.30
1903	Rose Lateral	do	5.0–6.0	25–37	1.60
1904	5 ditches	Santa Clara Valley			6.00
1904	Modesto [a]	Tuolumne River	22.0	78–242	.70
1904	do	do	33.0	260	1.70
1904	Turlock [a]	do	22.0	115–491	.80
1906	Moore	Cache Creek		86–116	4.80
1907	do	do	4.0	63–127	4.50
1907	Capay-Winters	do		40–80	6.40
1907	Central	Sacramento River	11.0		3.40
1908	San Joaquin and Kings Rivers	San Joaquin River	5.0	190–239	.45
1909	Modesto	Tuolumne River	22.0	532	.30
1909	Turlock	do	22.0	879	.20
1910	Modesto	do	18.0	793	.17

Average 5.93
Average omitting loss of 51.5 per cent on Vandalia Canal 4.24

[a] Seasonal.

THE CLEANING OF CANALS.

Wherever irrigation water carries much solid matter in suspension and when the climate is hot and the grade of canals is low, much trouble is experienced by irrigators in keeping canals free of silt and sand deposits and tules or other aquatic growth. In California the most trouble is found in the south. So serious is this question that several years ago Mr. C. E. Tait of this Office was detailed by the chief of irrigation investigations to make a special report on the best means of keeping canals clean. In connection with the preparation of this report Mr. Tait visited and examined the important canals of the entire Southwest, including Mexico. Although the field investigations on which this report will be based have not been entirely paid for out of the California cooperative funds, it is largely a cooperative report.

DRAINAGE OF IRRIGATED LANDS.

Investigation of questions relating to the drainage of irrigated lands have been confined chiefly to the section around Fresno and to Modesto and Turlock irrigation districts. The first work at Fresno consisted of a preliminary survey in 1902 and the preparation of a

preliminary plan for reclaiming about 28 square miles southwest of Fresno.[a] In 1907 and 1908 experiments were made on two tracts to determine and demonstrate the feasibility of drainage in reclaiming to their original high value the large areas of land of which these two tracts are typical. At the same time sufficient surveys were made to show that the area, for which a drainage system should be provided, approximated 200,000 acres, of which 30,000 acres, once some of the most productive land in Fresno County, worth at least $350 per acre, had already been rendered unproductive. The results of the investigations around Fresno, including an account of the beginnings of drainage work in Modesto and Turlock districts, were published in a bulletin of this Office,[b] by S. Fortier and V. M. Cone.

That drainage is as essential to the section around Fresno and to portions of Modesto and Turlock districts as irrigation and cultivation is no longer a question about which there can be the slightest doubt. That its accomplishment on any adequate scale at Fresno means the overcoming of local apathy and local opposition is equally plain. What will be done is problematical. The cost has been shown not to exceed $15 per acre for the entire area embraced. The drainage-district law is admirably adapted to the conditions present. No further work seems necessary from this Office until there shall have been developed a definite and general demand for carrying into effect the plans already outlined or some others equally effective. If such a demand develops all assistance possible will be rendered.

GENERAL IRRIGATION REPORTS ISSUED.

Including Bulletin No. 100, covering water-right conditions in California, the Office of Experiment Stations has issued or is preparing a number of general reports on irrigation in different localities in California in addition to the special reports on some particular phase of irrigation practice already mentioned or quoted from above. The titles of these reports and an outline of the matter covered by each follow:

Subterranean water supply of the San Bernardino Valley.—A discussion of the geologic formation and the underground water supplies of San Bernardino Valley and Temescal Creek and San Gabriel River drainage basins, together with a discussion of its utilization. By E. W. Hilgard.

Irrigation system on Stoney Creek.—A short description of the irrigation systems on this stream. By W. T. Clarke and C. W. Landis.

Irrigation in Santa Clara Valley.—This was a brief report, published in 1905, designed to show the extent to which irrigation is practiced in Santa Clara Valley, the amount of water used, the results of winter

[a] U. S. Dept. Agr., Office Expt. Stas. Circ. 50.
[b] U. S. Dept. Agr., Office Expt. Stas. Bul. 217.

irrigation of orchards, and the methods and cost of pumping water for irrigation in this valley. By S. Fortier.

The distribution and use of water in Modesto and Turlock irrigation districts.—This report was written in 1904, primarily to describe the difficulties encountered and finally overcome in the organization of these two districts and to point out such improvement in practice as seemed justified by the investigation on which it was based. It gave the history of the two districts, called attention to the excessive use of water, seepage losses, mistakes being made in the preparation of the land for irrigation, the ultimate need for storage for late irrigation water, the need and value of water measurements and records, and the pending need for drainage in some sections of the district. By Frank Adams.

Irrigation in Sacramento Valley.—This report gives the results of investigations of irrigation under Yolo County consolidated water system, of Yolo County; the Old Central Canal, of Glenn and Colusa Counties; the Butte County Canal, of Butte and Sutter Counties; and of irrigation along Stoney Creek in the vicinity of Orland. The introduction takes up the early efforts toward development of Sacramento Valley, soils, crops, relation of climate to irrigation, overflow lands, water supply, and the use of water, and urges the cooperation of State, Federal, and private enterprise in the irrigation and reclamation of the vast area included in this valley. By S. Fortier, assisted by O. W. Bryant, J. E. Roadhouse, A. E. Wright, and J. H. Barber.

Irrigation in San Joaquin Valley.—This report is a more or less detailed description of irrigation on all of the streams of San Joaquin Valley. It discusses the climate, soil, surface and underground water supplies, and the industrial development of the valley, and calls attention to the manner in which the best agricultural development of this large portion of California has been handicapped by the lack of irrigation laws that prohibit the waste of water and enable prospective irrigators to learn, in advance of building diverting works and then being stopped by court injunction, whether any water is available for appropriation. By V. M. Cone.

Irrigation in California.—This is a general report on irrigation in California, being one of a series of such reports covering all of the irrigated States and Territories of the West. Discusses climatic, topographic, and industrial situations, water resources by streams, lands, products, history of irrigation development, water laws, irrigation enterprises, irrigable land under existing systems, and cost of preparing land for irrigation. By F. W. Roeding.

Besides these a very complete description and discussion of the irrigation problems and possibilities of Imperial Valley, by C. E.

Tait, has been published as a Senate document.[a] This takes up the importance of irrigation, the construction of the Imperial irrigation system, the organization and management of the seven mutual water companies organized up to 1907, the preparation of land, and the application of water, the fertilizing value of silt, the crops grown and their water requirements, and the probable future irrigation organization of the valley. This report was preceded in 1904 by a brief discussion of irrigation in this valley by J. E. Roadhouse, of this Office.

REPORTS ISSUED 1900 TO 1910.

Since irrigation investigations were begun in California in 1900 forty-one reports dealing wholly or in part with irrigation in this State have been published by the Office of Experiment Stations. A complete list of these follows:

REPORTS PREPARED IN COOPERATION WITH THE STATE OF CALIFORNIA AND NOW IN PRESS, OR BEING PREPARED FOR PUBLICATION.

Irrigation in California. By F. W. Roeding.
The Use of Underground Water for Irrigation at Pomona. By C. E. Tait.
Irrigation in San Joaquin Valley. By V. M. Cone.
The Use of Concrete in Irrigation. By B. A. Etcheverry.

BULLETINS ISSUED BY THE OFFICE OF EXPERIMENT STATIONS PRIOR TO COOPERATIVE AGREEMENT WITH CALIFORNIA.

Farmers' Bulletin No. 116. Irrigation in Fruit Growing. By E. J. Wickson.
Farmers' Bulletin No. 138. Irrigation in Field and Garden. By E. J. Wickson.

REPORTS ISSUED WHOLLY OR IN PART IN COOPERATION WITH THE STATE OF CALIFORNIA.

Bulletin No. 145. Preparing Land for Irrigation and Methods of Applying Water. By agents of Irrigation Investigations.
Bulletin No. 158, Separate No. 2. Irrigation in Santa Clara Valley, by S. Fortier; Mechanical Tests of Pumping Plants, by J. N. Le Conte.
Bulletin No. 158, Separate No. 3. The Distribution and Use of Water in Modesto and Turlock Irrigation Districts, California, by Frank Adams; Relation of Irrigation to Yield, Size, Quality, and Commercial Suitability of Fruits, by E. J. Wickson; Irrigation Conditions in Imperial Valley, by J. E. Roadhouse.
Bulletin No. 177. Evaporation Losses in Irrigation and Water Requirements of Crops. By S. Fortier.
Bulletin No. 181. Mechanical Tests of Pumping Plants in California. By J. N. Le Conte and C. E. Tait.
Bulletin No. 203. Distribution of Water in the Soil in Furrow Irrigation. By R. H. Loughridge.
Bulletin No. 207. Irrigation in the Sacramento Valley, California. By S. Fortier.
Bulletin No. 217. Drainage of Irrigated Lands in San Joaquin Valley, Cal. By S. Fortier and V. M. Cone.
Circular No. 50. Preliminary Plans and Estimates for Drainage of Fresno District, Cal. By C. G. Elliott.
Circular No. 59. Progress Report of Cooperative Irrigation Investigations. By S. Fortier.

[a] Sixtieth Cong., 1st sess., Senate Doc. 246.

Besides these, the State of California, through the men employed in cooperation with this Office, has furnished part of the data for the following publications:

Farmers' Bulletin No. 263. Practical Information for Beginners in Irrigation. By S. Fortier.

Farmers' Bulletin No. 373. Irrigation of Alfalfa. By S. Fortier.

Farmers' Bulletin No. 392. Irrigation of Sugar Beets. By F. W. Roeding.

Farmers' Bulletin No. 404. Irrigation of Orchards. By S. Fortier.

O. E. S. Bulletin No. 229. The Delivery of Water to Irrigators. By Frank Adams.

Senate Document No. 246, 60th Congress, First Session. Irrigation in Imperial Valley. By C. E. Tait.

Bulletin No. 86, Separate No. 2. Duty of Water Under Gage Canal, Riverside, Cal. By W. Irving.

Bulletin No. 100. Report on Irrigation Investigations in California, under direction of Elwood Mead. Contains reports on the following: The Agricultural Situation in California, by Elwood Mead. The Irrigation Problems of Honey Lake Basin, by W. E. Smythe. Features of Water Rights of Yuba River, by Marsden Manson. Irrigation Investigations on Cache Creek, by J. M. Wilson. Report on Irrigation Problems in the Salinas Valley, by C. D. Marx. Irrigation from the San Joaquin River, by Frank Soule. Water Appropriation from Kings River, by C. E. Grunsky. A Study of Water Rights on the Los Angeles River, by Edw. M. Boggs. Problems of Water Storage on Torrential Streams of California as Typified by Sweetwater and San Jacinto Rivers, by James D. Schuyler.

Bulletin No. 104, Separate No. 2. Duty of Water Under Gage Canal, Riverside, California. By W. Irving.

Bulletin No. 108. Irrigation Practice Among Fruit Growers on the Pacific Coast. By E. J. Wickson.

Bulletin No. 119, Separate No. 2. Subterranean Water Supply of the San Bernardino Valley, California, by E. W. Hilgard. Duty of Water Under Gage Canal, Riverside, Cal., by W. Irving. Duty of Water in Tule River Basin, by A. E. Chandler.

Bulletin No. 133, Separate No. 2. Irrigation Systems on Stoney Creek, California. By W. T. Clarke and C. W. Landis.

THE DISTRIBUTION OF IRRIGATION BULLETINS.

The distribution of the bulletins published by the United States Department of Agriculture is in charge of the Division of Publications, at Washington, but applications for such bulletins from irrigators in California are usually received by the office at Berkeley and forwarded to Washington for attention if the bulletins requested are available. The especially practical nature of such recent bulletins issued as those dealing with the irrigation of alfalfa, orchards, sugar beets, and grain have greatly increased the number of applications received, and at least 50,000 bulletins have been sent out upon request of this Office to California irrigators during the past six months.

INVESTIGATIONS NOW UNDER WAY.

The limited funds at the disposal of the Office for cooperative irrigation investigations in California and the large opportunity for useful work made the task of selection a difficult one. Practically every irrigation condition known in this country is found here in large or small degree. While the annual precipitation ranges from nothing or only a trace on portions of the southern desert to excessive

amounts in the mountains of the north, it is a land of rainless summers. Without irrigation the moisture necessary to produce plant growth is either inadequate or comes to the land from one to six months before it is most needed. While thousands of acres are profitably farmed without irrigation, there are few sections of the State where some unirrigated crops do not suffer for lack of moisture at some period of their growth and when at least a light irrigation, if available, would not increase production. The question of irrigation is therefore state wide, and irrigation investigations and experiments designed either to extend the use of water or to bring about greater economy in its application will be necessary and profitable so long as there is a single acre-foot of water wasted that might be applied to the land.

STUDIES OF IRRIGATION POSSIBILITIES.

Studies of the possibilities of irrigation extension in localities in California where little or no irrigation is practiced were begun during the summer and fall of 1910 and will be continued the coming season. The sections designed to be covered by these studies are Russian River, Sonoma, and Napa valleys, in the north, and portions of Santa Barbara and Ventura counties, in the south. In these sections under consideration the belief generally exists that irrigation is not necessary, but this Office is proceeding on the theory that the absence of rainfall in the summer months leaves some crops with inadequate moisture at some period of their growth, and that the most profitable agriculture attainable demands that this deficiency be supplied when water is available. Preliminary investigations in the northern valleys in the summer and fall of 1910, especially about Ukia, disclosed a decided need for irrigation of such crops as alfalfa and corn and a considerable supply of water now wasting. Some of the most progressive farmers are using small supplies with very satisfactory results, both on alfalfa and orchards, but there is need for better methods and a more general recognition of the value of having adequate moisture in the soil at all times during the plant growing season. Cooperative demonstration experiments will be arranged with one or more farmers in each of the northern valleys in question early in 1911, with the purpose of both ascertaining and demonstrating what can be accomplished with irrigation. In the southern valleys under consideration, which will be covered by Mr. C. E. Tait, in charge of these investigations in southern California, sufficient preliminary work to determine the extent to which this Office can be of service have not yet been completed.

REVIEW OF OPERATIONS UNDER THE IRRIGATION DISTRICT LAW OF CALIFORNIA.

After many years of disfavor, the irrigation district law of California is again coming to be regarded by many as suited to communi-

ties desiring to own and manage their own water supplies. This is true of the northern part of the State more than of the southern part, where the mutual irrigation company has reached its highest development. Out of more than forty districts that were organized twenty or more years ago not more than half a dozen are to-day really in operation as districts, although a number of others are still legally in existence. The district form of organization is undoubtedly an almost ideal one where it is necessary to distribute the cost of irrigation works over a number of years, where it is economically desirable to cut up existing large holdings of unproductive dry-farmed land, and where the land is productive and the water supply secure and ample. The fact that many enterprises to which it was adapted were mismanaged and their bonds repudiated should not deter the further use of this form of organization where conditions are suited to it. It is the belief of many that the district law has been criticised and held responsible for results believed to be in no way due to it, and for this reason the task of reviewing historically the districts that have been organized and have failed and of thereby, in a measure, correcting existing misapprehensions has been undertaken. At present the statistical data have mainly been collected and the litigation examined and analyzed for all of the districts.

It is the belief of many in California that the sale of irrigation district bonds would be greatly facilitated if a law were enacted providing that before any such bonds are offered for sale there should be: First, a certificate from the State engineer that the water supply of the district in question is adequate, that the works proposed are sufficient and economical, and that the estimates will cover the cost of the completed system; second, that a certificate be issued by the attorney general that the water rights are valid and that the proceedings connected with the organization of the district and the offering of the bonds for sale have been in accordance with the law. With the present method of defining and acquiring rights to water in California, however, there might be considerable difficulty in giving a certificate of the validity of water rights.

BUSINESS ORGANIZATION OF THE MUTUAL IRRIGATION COMPANIES OF CALIFORNIA.

The mutual irrigation companies of southern California have worked out one of the most satisfactory forms of business organization thus far effected. These organizations are being extended in the State and also are being copied in a number of other States. To assist in this movement C. E. Tait is making an investigation of the organization of these companies.

STUDIES OF GRAPE IRRIGATION.

Owing to the inadequate funds, only preliminary work has been attempted during 1910, and this has been done by Frank T. Swett, of Martinez. The growing of grapes, either for table, raisins, or wine, is a principal California industry. They are grown with or without irrigation, and the question under consideration is, Where grown without irrigation is there a lack which more moisture could supply? Such a lack might be evidenced, as stated by Mr. Swett, by stunted growth, failure to bear satisfactorily, sunburn, small berries, susceptibility to insect pests, and, in extreme cases, to deficient sugar and death of vines. The question resolving itself into one of the amount of moisture best suited to vines, determinations of soil moisture have been made in vineyards in Imperial Valley, the large Guasti vineyard at Cucamonga, and at several points in San Joaquin and Sacramento Valleys. These determinations will be repeated next year, and the completed study will include consideration of such questions as the relative sugar and acid content of the product of irrigated and nonirrigated vineyards, also the relative keeping qualities and the relative quantity of juice per ton of grapes crushed.

INSTALLATION OF STANDARD MEASURING DEVICES.

This work contemplates the installation on our experimental plat on the university farm at Davis of a sample of each of the chief standard measuring devices used in delivering water to irrigators, with facilities for such testing of these devices as seem desirable, for checking the numerous conditions laid down for the weir formula, and for determining the proper constant for use with rectangular submerged orifices as installed for water delivery purpose. A reenforced concrete reservoir to give needed volume and head has been constructed with the financial assistance of the university farm, and a definite plan of installation has been laid out and begun. In addition, experimental work has been done in the construction of a special form of water meter for irrigation purposes, a sample of which will also be installed at Davis when perfected in some details.

IRRIGATION EXPERIMENTS AT DAVIS.

The irrigation experiments that have been conducted at the university farm at Davis for the past three years are being continued. For one or two more seasons most of our plat of 25 acres will be devoted to alfalfa irrigation, the questions under consideration being the relative yields produced from different amounts of water up to a total of about 4 feet in depth for the season and the relative effects of varying the quantity applied at each irrigation and the time of application. The results thus far obtained have been given already in the discussion of duty of water and the application of water to

crops. The corn and grain irrigation experiments begun in 1910 will also be continued through one or two more seasons. During the winter several plats that have been devoted to alfalfa for the past three years will be plowed up and seeded to wheat, in order to demonstrate the value of crop rotation under irrigation. An experiment in growing cowpeas as green fertilizer after a hay crop has been removed, as can be done with irrigation, will also be continued. The experimental work at Davis will hereafter be conducted with a greater degree of cooperation with the University of California than in the past. The profits from the irrigated crops grown on the experimental tract, which amount to about $400 per year, will by agreement hereafter be devoted to permanent irrigation structures in connection with the irrigation investigations, and the salary of our agent in charge will be paid equally by the university and this Office.

STUDIES OF IRRIGATION IN THE SIERRA FOOTHILLS.

During 1909 this Office investigated irrigation in the Sierra foothill region, including a general description of the foothill topography, climate, soil, area irrigated, methods employed, crops, water supply, water measurement, etc. From this brief investigation it was observed that, with the exception of a few small sections, irrigation in this region has not yet developed in the measure that is possible, either in extent or methods of application and measurement. A further study will be made of this region during 1911, and the results of the two seasons' work embodied in a circular of this Office.

CENSUS OF IRRIGATION IN CALIFORNIA.

In cooperation with the Bureau of the Census of the Department of Commerce and Labor this Office is engaged in taking a census of irrigation in California, the Office supervising the work and the Bureau of the Census paying the salaries and expenses of the necessary agents. Similar work is being done by the Bureau of the Census and the Office of Experiment Stations in all of the irrigated States of the country. While heretofore the census of irrigation has dealt primarily with purely statistical matters, the irrigation census of 1910 will go fully into details of the finance and management of irrigation enterprises and be the most complete report on the status of irrigation ever undertaken for the entire country. It is for this reason that it has been combined with a study along similar although more extensive lines being made by the Office of Experiment Stations. The information irrigators are required by law to furnish is covered by 10 different schedules, 1 each being provided for Reclamation Service projects, Carey Act projects, irrigation districts, cooperative or mutual enterprises, corporate enterprises, private or partnership ditches, private pumping plants, private reservoirs, private flowing

wells, rice irrigation companies, and private plants irrigating rice. The special field agents that have been appointed are in nearly every case present or former agents of this Office, and these men are calling upon every active ditch company in California and Nevada.

PRESENT STATE OF IRRIGATION DEVELOPMENT IN CALIFORNIA.

To give an accurate account in detail of the present extent of irrigation development in California would require a class of information not in possession of this Office. Much of the information necessary for such an account was, however, collected. Based on such information and eliminating projects still in the promotion stage, a conservative estimate places at 750,000 acres the area for which construction to provide irrigation water is now under way. Of this area about one-third is in southern California and the remainder north of Techachapi.

Of the area now being brought underway in southern California, the principal acreage is under the various mutual water company systems of Imperial Valley, the Yuma project of the United States Reclamation Service, the new municipal aqueduct being built to supply water for use within the city of Los Angeles, but which will irrigate a large area outside of the city pending the increased needs by the city, and the southern coastal regions where development has already reached a high state. In the latter sections it is the increase in pumping plants, notably around Corona, Chino, Pomona, Whittier, Covina, Anaheim, Fullerton, Riverside, and San Jacinto Valley, that is increasing irrigation. At Redlands the most notable addition will come by the construction of a large multiple-arch dam in the San Bernardino Mountains to supply water to the various mutual water companies that two years ago acquired the property of the Bear Valley Irrigation Co., from which they had theretofore been purchasing water, but which they have now mutualized. In San Diego County the matter of chief interest from the standpoint of irrigation engineering is the raising by 15 feet of the height of Sweetwater Dam.

The rapid irrigation development now taking place in southern California is the more surprising in view of the popular impression that all available water was long ago utilized in that section of the State. An account of it is submitted to show the great value attached to water there and the extreme efforts being put forth to acquire an increased supply.

Turning north of Tehachapi, in some sections development is not unlike that of the South. Pumping for water is being increasingly resorted to in the foothill sections of Kern, Fresno, and Tulare Counties, and one of the largest pumping irrigation systems in the West is now in operation in San Joaquin County, the water supply

being the San Joaquin River. The lower San Joaquin Valley is fortunate in having a plentiful supply of underground water of good quality and at relatively small distance below the ground surface. In the belt around Porterville, Lindsay, Exeter, and Lemon Cove, Mr. V. M. Cone, of this Office, finds it now considered profitable to pump against a head of 400 to 500 feet for citrus trees. Outside of pumping very little irrigation development is being accomplished in the lower San Joaquin Valley, owing to exhaustion of the low-water flow of the streams and the difficulties of utilizing flood waters that now go to waste for want of adequate water-right laws under which they can be acquired. In the upper San Joaquin a steady increase in the irrigated area is being brought about in Modesto and Turlock irrigation districts, and what is perhaps the most notable accomplishment in the entire San Joaquin Valley is the recent successful organization of the Oakdale and South San Joaquin irrigation districts, in San Joaquin and Stanislaus Counties. These two districts have jointly purchased for $650,000 the old Turlock irrigation system at Oakdale, with its valuable water rights in Stanislaus River, and have together voted bonds to the extent of $3,475,000 for the construction of reservoirs, canals, and distributaries to irrigate 140,000 acres of land. In Sacramento Valley, which has been more backward than any other large part of the State in recognizing the need and advantages of irrigation, the largest single unit is that of the Sacramento Valley Irrigation Co., at Willows, which as the successor of the old Central Irrigation District formed under the original Wright Act is constructing works to cover a large area of the valuable land of this valley. At Orland the Orland project of the United States Reclamation Service, covering 14,000 acres in its first unit, was 77 per cent completed October 1 and ready for settlement. Other areas of more or less size are also being put under irrigation and sold to settlers in Sacramento Valley. The opening of the Western Pacific Railway over the Sierra Nevada at a considerable distance north of any other transcontinental line has given a new impetus to development, which must be largely through irrigation, in the northeastern counties of Plumas, Lassen, and Modoc. In the latter county additional land is to be irrigated by the Klamath project of the Reclamation Service. Plans of the Reclamation Service for reclaiming and ultimately irrigating 27,000 acres of Klamath Marsh and about an equal area of Tule Lake, all in California, have already been approved by the Secretary of the Interior, and bids for construction in connection with the latter were opened November 1. A third subproject included in the plans of the Reclamation Service, but not yet approved, provides for the irrigation of 10,400 acres in California south and west of Clear Lake reservoir.